Text messaging interventions for improvement in physical activity and sedentary behaviour in youth

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Systematic review

The effects of text messaging interventions to improve physical activity and sedentary behaviour in youth: A systematic review

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Abstract

Background

The use of text messages (SMS) to change physical activity (PA) and sedentary behaviour (SB) in youth is of interest due to the need for novel, more effective intervention approaches. Previous reviews have examined a variety of technology-based interventions and their impact on different health behaviours but evidence regarding the impact of just SMS on PA and SB is lacking. Thus, the current systematic review aims to assess the effectiveness of SMS interventions for improving PA and SB in youth.

Methods

Authors systematically searched electronic databases from March to November 2017. Citations were sifted using additional reviewers and a qualitative synthesis of eligible studies was conducted using piloted data extraction forms. To be eligible for inclusion, studies had to be of randomised controlled or quasi-experimental design, incorporate SMS, involve adolescents between the ages of 10 and 19 and assess at least one PA or SB outcome. Risk of bias was assessed using the Cochrane Collaboration's Risk of Bias tool.

Results

Thirteen studies reporting on 11 interventions were included in the qualitative synthesis. Studies included interventions that were conducted in schools, online or face-to-face. Studies were of high heterogeneity with regards to study duration, participant characteristics, intervention content and outcome measures. Findings were equivocal with regards to intervention effectiveness for PA and SB. Seven interventions resulted in an improvement for PA and six for SB. All studies were judged to be of high risk of bias for at least one item.

Conclusions

Some studies in this review showed promising results for using SMS to improve PA and SB in youth. High heterogeneity of design and outcome measures precluded data pooling and conclusions as to which specific intervention elements are linked to increased effectiveness cannot be drawn. The authors propose incorporating the following elements in future

studies: specific focus on desired health behaviour; mixed methods design; include long-term follow-up; include self-monitoring, goal setting and feedback; combine SMS with a mobile app; send 3 or more SMS per week. More rigorous studies are needed to explore the relationship between intervention effectiveness and specific intervention components such as content and delivery.

Keywords

Systematic review, Exercise, **sedentary behaviour**, **behaviour change theory**, Text messaging, Cell Phone, Telemedicine, **intervention**, Adolescent

Introduction

Participating in sufficient levels of physical activity is essential to reduce the risk of all-cause mortality and cardiovascular disease [1,2]. For adolescents, it is recommended that they undertake at least 60 minutes of moderate to vigorous physical activity (MVPA) per day [3]. Unfortunately, few adhere to these current activity recommendations with adolescence characterized by declining PA levels in conjunction with increased sedentary time, despite calls for sedentary time to be minimized [4]. For instance, findings from Europe suggest that 83.2% of adolescents aged 11 to 17 don't achieve a minimum of 60 minutes of MVPA per day whilst globally, it has been estimated that 80.3% of adolescents are insufficiently active [5]. Moreover, global data suggests that adolescents spend 57% of their time in sedentary activities with 40% of adolescents spending 3 or more hours watching TV on weekdays increasing up to 50% on weekends [6,7]. These findings are particularly concerning as SB is associated with various aspects of poor psychological and physiological health as well as all-cause and cardiovascular disease-related mortality [8–11]. Conversely, increased PA improves adiposity, blood lipid profile, blood pressure, insulin resistance, aerobic fitness and bone health [12] while also reducing premature all-cause mortality [13]. Given these relationships both SB and PA are important therapeutic targets to reduce lifestyle induced non-communicable diseases and especially during adolescence, where behaviours developed in younger ages are likely to continue into later life [14,15]. In order to counteract physical inactivity and sedentary behaviour nonetheless, there is a need for research to generate new strategies to modify these unhealthy behaviours given the inconsistent success of traditional intervention approaches [16].

Mobile health (mHealth) which draws upon mobile devices for health-related applications has emerged as a promising tool for health-related behavioural interventions [17]. Mobile phones are used by all age groups with more than 90% of UK children aged 12 to 15 currently using them [18]. Such high usage suggests that these mobile devices may offer a cost-effective and acceptable means for delivering health behaviour change interventions that can fit within people's everyday lives and have population wide-reach. Unsurprisingly mHealth approaches are also being used to provide health care services worldwide, including in Africa, Asia and South America [19]. In the UK, the National Health Service is

employing the text-messaging system Florence™ to support patients in monitoring, managing and improving their health [20]. mHealth systems can also be used to send appointment or medication reminders to support health care workers by providing training, decision making and communication tools as well as to implement health promotion and education interventions [19,21]. However, there is a lack of evidence regarding the effectiveness of mHealth interventions on behaviour change and health outcomes [19,22,23]. Unfortunately, research which has examined the effects of SMS interventions upon PA and SB in youth is also scant.

Previous systematic reviews and meta-analyses involving adolescents have included a variety of technologies, such as apps, e-mail, video games and websites when reviewing the evidence on the most effective means of improving PA and SB [24–32]. However, none of these reviews have assessed the effectiveness of SMS in isolation. Moreover, reviews have included a number of outcomes such as disease state or medication adherence [25,33–36] and have focused on several different health behaviours such as smoking and diet [25,27,29–32,34]. As such, evidence is lacking which has examined the efficacy of mobile devices to influence PA and SB. Furthermore, and to the best of our knowledge, existing systematic reviews and meta-analyses involving adolescents and SMS as a means for improving PA and SB have not explored the use of theoretical frameworks [24,30–32,34–37].

As evidence has shown increased effectiveness of health interventions using a behavioural theory framework [38,39], it is surprising that many interventions have been developed without proper underpinning theory. Even in those studies that suggest their intervention was informed by appropriate theory, the specific application of theory often remains unclear [40,41]. As well as evaluating the evidence of effectiveness of interventions using mobile phones for improving PA and SB, it is important to evaluate the theory and behaviour change techniques (BCTs) which have been used to develop these interventions. Providing this information is essential for health care practitioners to ensure that future mHealth interventions are effectively implemented. To provide this evidence, this review aimed to systematically identify m-Health studies that have been developed to increase PA levels and to reduce SB in adolescents. A subsequent aim was to identify the theory and BCTs used in

these studies. Findings from this review are expected to provide insight into the development of future m-health interventions in order to maximize their effectiveness.

Methods

All data is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines [42].

Eligibility criteria

Experimental (randomized controlled trial or quasi-experimental design) studies were included if they involved or reported data separately for participants between the ages of 10 and 19 with or without known morbidities, used text-messaging via a mobile or smartphone within the intervention, both in addition to other intervention components or on its own, employed usual care, another intervention or no intervention as comparator and assessed at least one outcome related to PA and/or SB. All outcomes related to PA and SB, such as step count, moderate PA (MPA), and screen time, as well as all subjective and objective outcome measures were eligible for inclusion. Further, only studies that were written in the English language and where full text was available were included. Studies were excluded if they solely used other technologies such as apps, websites or email.

Information sources

A systematic search of the following electronic databases was conducted in March 2017 and updated in November 2017: Web of Science (coverage 1864-2017), PubMed (1809-2017), Medline (1946-2017), CINAHL Complete (1937-2017), PsycINFO (1800s-2017; not available for search update and replaced by PsycARTICLES 1894-2017) and SPORTDiscus (1930-2017). All databases except PubMed (7th November 2017) were last searched on the 8th November 2017. During the initial search, KL searched bibliographies and contacted corresponding authors of eligible studies. Bibliographies of existing systematic reviews and meta-analyses identified during the initial search process were also screened for eligible studies [24–37,43,44].

Search

Search terms and combinations of the electronic database search are shown in Table 1.

Table 1. Electronic database search terms and combinations.

Category		Search term		Search term
Intervention mode	1	„mobile phone“	9	mHealth
	2	smartphone	10	telehealth
	3	„cell phone“	11	“online health”
	4	„handheld device“	12	e-Health
	5	text-messag*	13	eHealth
	6	SMS	14	“mobile health”
	7	“messag* service“	15	“digital media”
	8	“messaging system”	16	ICT
	17	[1 - 16] combined with OR		
Study design	18	„randomised controlled“	21	„controlled trial“
	19	„randomized controlled“	22	quasi-experimental
	20	RCT		
	23	[18 - 22] combined with OR		
Participants	24	adolescen*	30	pediatric
	25	youth	31	teen*
	26	“young people”	32	„school age“
	27	“young adult*”	33	„school-aged“
	28	child*	34	highschool
	39	paediatric	35	„secondary school“
	36	[24 - 35] combined with OR		
Behaviour	37	activity	41	“behaviour change”
	38	sport	42	lifestyle
	39	exercise	43	sedentary
	40	health*	44	sitting
	45	[37 - 44] combined with OR		
	46	[17, 23, 36, 45] combined with AND		

* Asterisk used to search for words beginning with these letters.

Study selection

Study citations from the electronic search were imported into the reference manager software Zotero (Version 5.0, online and standalone). KL manually removed duplicates. For the initial search, KL and HF independently screened titles and abstracts of all remaining

studies. Following the search update, KL and DB independently reviewed new titles and abstracts with the full texts of relevant titles obtained to confirm eligibility. KL and HF (DB for search update) discussed discrepancies until consensus was reached. KL hand searched bibliographies of eligible studies and contacted corresponding authors for additional manuscripts. All eligible studies were then included in qualitative synthesis.

Data collection process

Data extraction was conducted based on the Cochrane Collaboration's Data Extraction Template for Included Studies (Version 1.8) [45]. Items of interest for this review such as the content of SMS and interactivity were added to the Cochrane Data Extraction Template. KL piloted the updated template on two randomly chosen studies eligible for this review. Subsequently, the piloted form was revised where necessary. Thereafter, KL and HF (DB after search update) independently extracted required data using the revised form. Extractions were compared and discussed until consensus was reached for all items. Content was then synthesised for analysis.

Data items

Data extracted included (a) general study information (such as country, aims, target health behaviour); (b) methods (such as study design, duration of intervention); (c) participants (such as population description, number recruited, age, sex, health status); (d) intervention and control group(s) (such as name of group, number of participants randomized, intervention mode, content, use of theory, message content, frequency, device, interaction, adherence); (e) outcomes (assessed PA/SB outcomes, method of PA/SB outcome assessment, timing of PA/SB outcome assessment); (f) results and conclusion (including additional results information and relevant conclusions); (g) other information (including funding source and conflicts of interest). Where data was missing or clarification was sought, study authors were contacted. Where multiple studies reported on multiple follow-up periods or outcomes of the same intervention, outcomes from the longest follow-up time point available for each outcome were extracted.

Risk of bias in individual studies

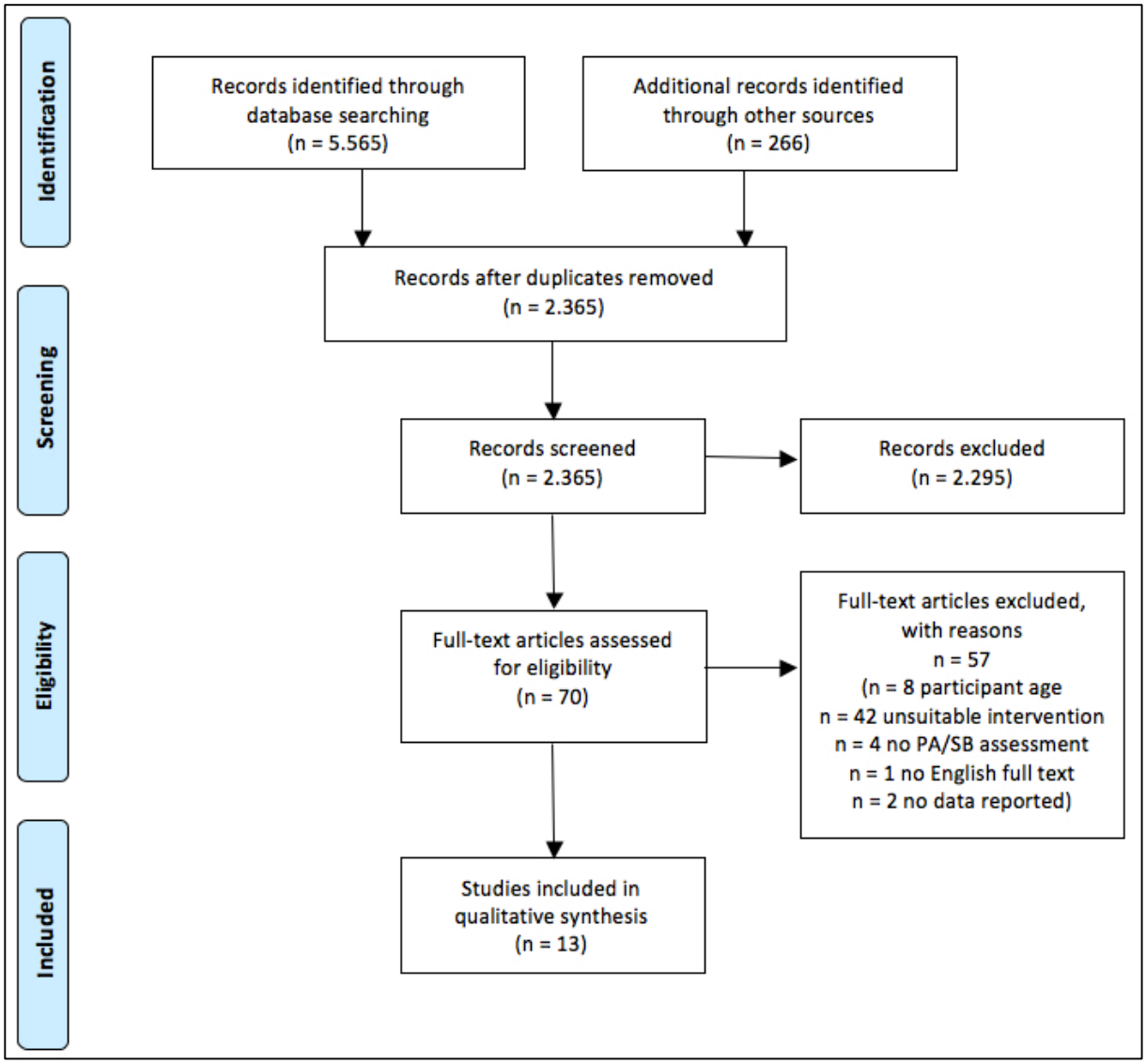
Assessment of risk of bias was conducted at study level. KL and HF (DB after search update) reviewed all included manuscripts using the Cochrane Collaboration's risk of bias assessment tool [46]. KL employed this assessment tool using RevMan (software, version 5.3). Due to the nature of behavioural interventions, blinding of participants and personnel is challenging and rarely incorporated [47]. This item was therefore not included in the assessment. The following remaining domains were judged: selection bias (random sequence allocation, allocation concealment), detection bias (blinding of outcome assessment), attrition bias (incomplete outcome data), reporting bias (selective reporting) and other bias. KL and HF (DB after search update) ranked each item as high, low or unclear risk for each study and discussed discrepancies until consensus was reached.

Results

Study selection

The electronic database and hand search produced 5,565 and 266 studies respectively. After removal of duplicates, 2,365 studies were screened. 2,295 records were excluded and 70 full-text articles assessed. 13 eligible full text articles assessing 11 different interventions remained and were included in qualitative synthesis. A flowchart of the systematic literature search is displayed in Figure 1.

Figure 1.


Identification
Screening
Eligibility
Included
Records identified through database searching (n = 5.565)
Additional records identified through other sources (n = 266)
Records after duplicates removed (n = 2.365)
Records screened (n = 2.365)
Records excluded (n = 2.295)
Full-text articles assessed for eligibility (n = 70)
Full-text articles excluded, with reasons
n = 57
(n = 8 participant age
n = 42 unsuitable intervention
n = 4 no PA/SB assessment
n = 1 no English full text
n = 2 no data reported)
Studies included in qualitative synthesis (n = 13)

Study characteristics

Study characteristics of included studies are shown in Table 2 and 3. Twelve studies targeted PA [48–59] and seven SB [48–51,54,59,60]. Additionally, most studies also focused on dietary behaviours [49–52,54,57,59,60].

Some studies focused on participants with specific characteristics, including those not meeting current PA guidelines [48,53], not participating in physical education lessons or organised sports [54], having type 1 diabetes [56], being at high risk for diabetes [57], having a Body Mass Index ≥ the 85th percentile [49,59] and being ≥ 1 year post cancer therapy [55]. When including overweight or obese participants, rates ranged between 23.7% [52] and 55% [49] for overweight and between 6.7% [52] and 45% [49] for obesity. Mean age of participants ranged between 12.5 [52] and 17.3 [58]. One intervention only included female participants [50,51,54]. Twelve studies consisted of ≥ 50% female participants [48,50–60].

309 Table 2. Study characteristics of included studies: Sample and outcomes.

Author, year, country	N	Design	Age	PA/SB outcomes	Assessment
Brannon et al., 2017, U.S.	10	N-of-1 RCT	16.7 ± 0.95	MVPA min/day, SB min/day	Objective
Chen et al., 2017, U.S.	40	RCT	14.9 ± 1.7	PA days/week, TV/computer hours/day	Self-report
Dewar et al., 2013, Australia	357	Group RCT	13.2 ± 0.5	Accelerometer counts/min, % MVPA, screen time min/day	PA: objective SB: self-report
Dewar et al., 2014, Australia	357	Group RCT	13.2 ± 0.5	% MPA, VPA, MVPA; SB min/day	PA: objective SB: objective + self-report
Ermetici et al., 2016, Italy	487	Non-randomised CT	12.5 ± 0.4	MVPA hours/week, screen time hours/day	PA: objective + self-report SB: self-report
Lana, Faya-Ornia & López, 2014, Spain & Mexico	2001	RCT	Pre 13.26 ± 1.03 Post 12.91 ± 0.77	SB (less than 360 min PA/week)	Self-report
Lau et al., 2012, Hong-Kong	78	Non-randomised CT	CG 13.26 ± 1.14 IG 12.29 ± 0.87	PA level last 7 days	Self-report
Lubans et al., 2012, Australia	357	Group RCT	13.18 ± 0.45	Accelerometer counts/min, MVPA min/day, SB min/day	PA: objective SB: self-report
Mendoza et al., 2017, U.S.	60	RCT	16.6 ± 1.5	MVPA min/day, SB min/day	Objective
Newton, Wiltshire & Elley, 2009, New Zealand	78	RCT	14.4 ± 2.37	Step count, MVPA min/week	Objective + self-report
Patrick et al., 2013, U.S.	101	RCT	14.3 ± 1.5	MVPA min/week, SB hours/day	Self-report
Sirriyeh, Lawton & Ward, 2010, Great Britain	120	RCT	17.3 ± 0.68	MVPA MET minutes/week	Self-report
Straker et al., 2014, Australia	44	Within-subject CT	14.1 ± 1.6	SB, light, moderate, vigorous PA min/day	Objective

310

311 *N = number of participants randomised. Age in mean ± standard deviation. RCT =*
312 *randomised controlled trial. MPA = moderate physical activity. VPA = vigorous physical*
313 *activity. MVPA = moderate to vigorous PA.*
314
315 Table 3. Study characteristics of included studies: Intervention and comparator.

Author, year	Intervention duration	TM intervention	Comparator(s)
Brannon et al., 2017	24 days	TM + mobile app	Mobile app only
Chen et al., 2017	6 months	TM + FitBit and app + online program	Online program + pedometer + diary
Dewar et al., 2013	12 months	TM + school program	Waitlist condensed intervention
Dewar et al., 2014	12 months	TM + school program	Waitlist condensed intervention
Ermetici et al., 2016	24 months	TM + school program	No information
Lana, Faya-Ornia & López, 2014	9 months	TM + online program	Online intervention, limited access online intervention
Lau et al., 2012	8 weeks	TM + online program	No intervention
Lubans et al., 2012	12 months	TM + school program	Waitlist condensed intervention
Mendoza et al., 2017	10 weeks	TM + FitBit and app + Facebook group	Standard care
Newton, Wiltshire & Elley, 2009	12 weeks	TM + pedometer	Standard care
Patrick et al., 2013	12 months	TM + online program	Online program, online program + group sessions + phone calls, usual care
Sirriyeh, Lawton & Ward, 2010	2 weeks	TM only	Neutral TM
Straker et al., 2014	12 months	TM + group sessions + phone calls	No intervention

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317
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Intervention design and content

Two interventions included SMS in addition to a school program [50–52,54]. Five with an online intervention [49,53,55,57,60] and others in addition to pedometers [56], group sessions and telephone calls [59], apps [48,49,55] and FitBits [49,55]. Only one intervention consisted solely of SMS [58]. Two interventions consisted of different types of SMS [48,58]. Depending on group allocation, one employed SMS focusing on affective and/or instrumental beliefs [58], whereas the other involved SMS from different senders including a parent, peer or behavioural health specialist [48]. School-based interventions using SMS included elements such as sport and PA opportunities, educational (group) seminars, provision of healthy foods, self-monitoring tools and printed or email materials promoting healthy lifestyles [50–52,54]. One also used a Facebook group to promote healthy lifestyles and keep participants informed about the intervention [52]. Interventions that included an online component also consisted of a variety of elements: forums, diet analysis, videos, educational games, challenges, educational materials, expert advice, behavioural skill training, goal-setting, monitoring, feedback and tutorials on behaviour change strategies [49,53,57,60]. One study included access to a private Facebook group, which provided rewards for achievements, encouragement and a discussion board, as well as using FitBits and an app to monitor progress towards individualised goals [55]. In another study, participants wore pedometers that were used to encourage PA and facilitate recording progress [56]. Another study included group sessions that provided education on health behaviours and achieving successful behaviour change. In this study, participants also received phone coaching during the 12-month maintenance period post intervention [59]. One study using an app for monitoring and reporting of PA also included autonomous and external goal setting as well as daily feedback [48]. Depending on which condition participants were assigned for that day, SMS were sent by a behavioural health specialist, parents, or a peer [48].

Content of SMS

SMS were used to encourage, motivate, reinforce and prompt participants to be physically active or maintain their current positive behaviour changes [48–51,53–56,59,60]. Some studies provided participants with suggestions for healthy lifestyle behaviours [48,49,59].

In addition to promoting PA, one study also employed SMS to provide participants with health behaviour information, behavioural skills, solutions for PA barriers, to reinforce the benefits of PA and to build rapport with a virtual friend [53]. SMS were also used for feedback [48,53], which in one study depended on the participant's goal attainment [48]. SMS also included statements from testimonials as well as messages targeting intrinsic motivation and reflective questioning [59]. SMS were also used to reduce risk behaviours [60]. Two interventions employed SMS aiming to increase participant self-efficacy [59,60]. Three interventions sent SMS related to goal-setting, such as the participants' specific weekly challenges [55,57,59]. In addition to this, one intervention included affective SMS for encouragement and as a reminder of PA goals. In this intervention, SMS sent in intervention week 2 were based on the participants' step counts from week 1 [55]. Another study sent SMS regarding affective and/or, depending on the intervention group, instrumental gains associated with regular PA. These included messages regarding the benefits of being active, such as physical and psychological improvements [58]. Three studies used SMS to remind participants to follow the intervention protocol, such as logging on to the intervention website or wearing an activity tracker [49–51,53,54,56,57].

Theory derivation

Three studies based their interventions on the Transtheoretical Model (TTM) of behaviour change or Stage of Motivational Readiness for Change (SOC) model [53,57,60]. One study used the SOC model to tailor intervention content and presentation, such as by adapting TM and website content according to the participant's stage of motivational readiness [53]. Participants in pre-contemplation, contemplation and preparation stage were given information on benefits and barriers of PA, opportunities for PA, goal setting as well as PA planning. Participants classed in the action stage were provided with monitoring tools and information to prevent relapse [53]. In addition to the TTM, one study also used the I-Change, Attitude - Social influence - Self-efficacy, Model and addressed attitude, social influence and self-efficacy. They emphasised advantages of following the recommendations and disadvantages of risk behaviours, created a healthy online social environment and strengthened skills to avoid risk behaviours [60].

Moreover, one study used both behavioural determinants models and TTM to guide intervention design [57]. One study employed affective and instrumental beliefs as well as

382 the Theory of Planned Behaviour (TPB) [58]. Two interventions were informed by Social
383 Cognitive Theory (SCT) [49–51,54]. One focused on self-efficacy, outcome expectation, self-
384 monitoring, skill mastery and self-regulation capabilities [49]. Another employed SCT by
385 planning social support or change, providing general encouragement and information about
386 the behaviour health link as well as identifying barriers and strategies to overcome these.
387 Specifically, outcome expectations, social support and self-efficacy were targeted [50,51,54].
388 Self-determination theory (SDT) formed the basis for two interventions [55,59], with one
389 also using goal-setting theory [59]. This intervention focused on the provision of a need-
390 supportive environment to achieve greater self-determination, autonomous motivation and
391 consequently greater engagement with the desired behaviour(s). Goal-setting theory was
392 employed to increase autonomous and intrinsic goal setting in order to predict greater goal
393 attainment and engagement with desired behaviours [59]. The other focused on
394 psychological needs that influence motivation: competence, autonomy and relatedness. The
395 FitBit and app aimed to increase competence and autonomy by proving opportunities to set
396 personalised goals and monitor progress. The Facebook group aimed to enhance relatedness
397 by providing support [55]. Cybernetic Control Theory (CCT) was used by one study, which
398 included self-regulation strategies defined by goal-setting, self-monitoring, goal review and
399 feedback [48]. Two studies did not provide any information regarding theory derivation.
400 Authors were contacted and lack of a specific theory base informing SMS was confirmed
401 [52,56].
402

403 ### SMS delivery and interactivity

404 In three studies, SMS were sent weekly [55,56,60]. Two sent daily SMS [48,58]. Another sent
405 SMS only on weekdays [53]. Two sent 3 or more each week [52,57]. Two studies only sent
406 SMS during the maintenance period following the intervention [49,59]. In one, the number
407 of SMS was reduced from 3 to 1 per week and finally to one per month [59]. In the other,
408 SMS were sent bi-weekly during a 3-month maintenance phase [49]. Another intervention,
409 increased the frequency of SMS from weekly up to twice per week [50,51,54]. Five studies
410 specified the time of SMS delivery [48,50–52,54,58,59]. SMS were sent at 4pm at the end of
411 the school day to minimise the risk of cross-contamination [58], close to meal times [52],
412 between 7 and 8pm [48] and depending on the SMS content, such as immediately after
413 school when encouraging PA [50,51,54]. Another study sent SMS on weekday evenings at

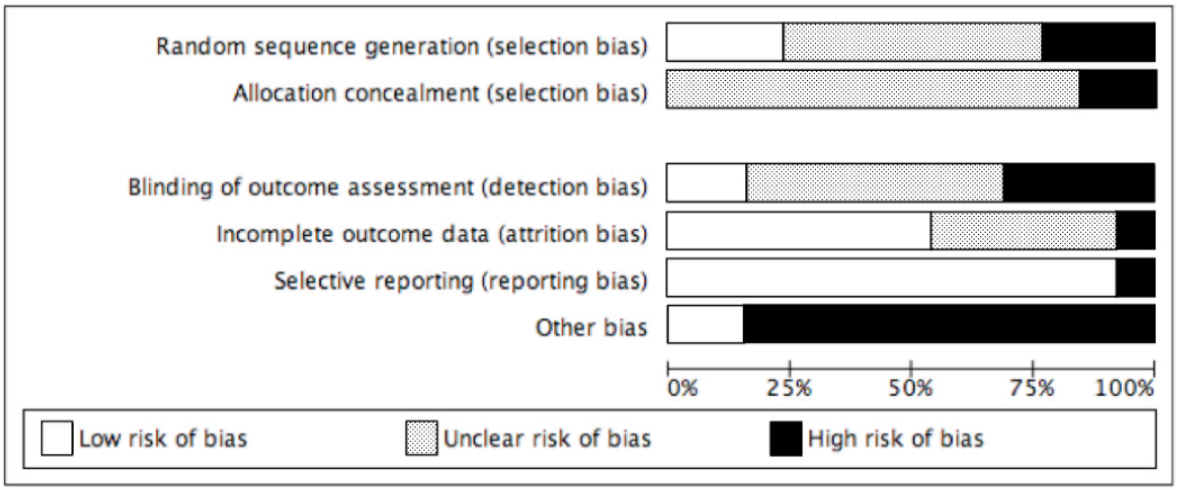
6pm and at 12pm on weekends. Here, participants were able to choose on which days they wished to receive SMS [59].

Three studies gave participants the possibility to interact with the research team and reply to SMS [53,57,59]. Responding was optional, however one study provided a monetary incentive to do so [53]. Another study also allowed interactivity, however participants would only receive one reply [59].

Risk of bias within studies

Five studies referred to previously published study protocols [50,51,54,59,60]. These were used to obtain missing information needed for the risk of bias assessment. The judgement of each risk of bias item across studies can be found in Figure 2. Tables 4 and 5 show the support for judgement of each item and study.

Figure 2.



437 Table 4. Support for judgement of risk of bias per item and study. Random sequence
438 generation, allocation concealment, blinding of outcome assessment.
439

Author, year	Random sequence generation	Allocation concealment	Blinding of outcome assessment
Brannon et al., 2017	**Unclear** Not enough information	**Unclear** Not enough information	**Unclear** Not enough information
Chen et al., 2017	**Low** Randomisation using computer program	**Unclear** Not enough information	**Unclear** Not enough information
Dewar et al., 2013	**Unclear** Not enough information	**Unclear** Not enough information	**High** Blinded at baseline only. Outcomes likely to be influenced by lack
Dewar et al., 2014	**Unclear** Not enough information	**Unclear** Not enough information	**Unclear** Not enough information
Ermetici et al., 2016	**High** No randomisation	**High** No randomisation	**Unclear** Not enough information
Lana, Faya-Ornia & López, 2014	**Low** Randomisation using computer program	**Unclear** Not enough information	**Unclear** Not enough information
Lau et al., 2012	**High** No randomisation	**Unclear** Not enough information	**Unclear** Not enough information
Lubans et al., 2012	**Unclear** Not enough information	**Unclear** Not enough information	**High** Blinded at baseline only. Outcomes likely to be influenced by lack
Mendoza et al., 2017	**Unclear** Not enough information	**Unclear** Not enough information	**High** Un-blinded RCT
Newton, Wiltshire & Elley, 2009	**Unclear** Not enough information	**Unclear** Not enough information	**Low** Assessors blinded at follow-up
Patrick et al., 2013	**Unclear** Not enough information	**Unclear** Not enough information	**Unclear** Not enough information
Sirriyeh, Lawton & Ward, 2010	**Low** Randomisation using random number generator	**Unclear** Not enough information	**Low** Assessors blinded at follow-up
Straker et al., 2014	**High** Within-subject waitlist study design	**High** Within-subject waitlist study design	**High** Outcomes likely to be influenced by lack of blinding

440 Table 5. Support for judgement of risk of bias per item and study. Incomplete outcome data,
441 reporting bias, other bias.

Author, year	Incomplete outcome data	Reporting bias	Other bias
Brannon et al., 2017	**High** High amount of missing data	**Low** All outcomes reported	**High** Compliance bias (use of incentives)
Chen et al., 2017	**Unclear** Insufficient reporting of reasons for missing data	**Low** All outcomes reported	**High** Response bias (use of self-report), compliance bias (use of rewards)
Dewar et al., 2013	**Low** Missing outcome data balanced and similar reasons across groups	**Low** All outcomes reported	**High** Response bias (use of self-report)
Dewar et al., 2014	**Low** Missing outcome data balanced and similar reasons across groups	**Low** All outcomes reported	**High** Response bias (use of self-report)
Ermetici et al., 2016	**Unclear** Insufficient reporting of reasons for missing data	**Low** All outcomes reported	**High** Response bias (use of self-report)
Lana, Faya-Ornia & López, 2014	**Unclear** Insufficient reporting of attrition, exclusions and reasons	**Low** All outcomes reported	**High** Response bias (use of self-report)
Lau et al., 2012	**Low** Missing outcome data balanced and similar reasons across groups	**Low** All outcomes reported	**High** Response bias (use of self-report), compliance bias (use of incentives)
Lubans et al., 2012	**Low** Missing outcome data balanced and similar reasons across groups	**Low** All outcomes reported	**High** Response bias (use of self-report)
Mendoza et al., 2017	**Low** Missing outcome data balanced and similar reasons across groups	**Low** All outcomes reported	**Low** Appears free of other sources of bias
Newton, Wiltshire & Elley, 2009	**Low** Missing outcome data balanced and similar reasons across groups	**Low** All outcomes reported	**High** Response bias (use of self-report)
Patrick et al., 2013	**Unclear** Insufficient reporting of reasons for exclusions and drop-outs	**Low** All outcomes reported	**High** Response bias (use of self-report)

Sirriyeh, Lawton & Ward, 2010	**Unclear** Insufficient reporting of reasons for exclusions and drop-outs	**High** Missing mean and SD of MET minutes at time point 1	**High** Response bias (use of self-report), analytical bias (removal of outliers)
Straker et al., 2014	**Low** Missing outcome data balanced and similar reasons across groups	**Low** All outcomes reported	**Low** Appears free of other sources of bias

Several studies were rated as unclear selection bias with regards to random sequence allocation [48,50,51,54–57]. Three were rated high risk [52,53,59] and three low risk [49,58,60]. Most studies also tended to be of unclear risk of selection bias with regards to allocation concealment [48–51,53–58,60]. Two studies were rated as high risk for this item [52,59]. Seven studies were ranked to be of unclear risk of detection bias [20, 21, 23–26, 30], with four judged as high risk [50,54,55,59] and two as low risk [56,58]. With regards to attrition bias, seven studies were judged to be of low risk [50,51,53–56,59], whereas five were ranked as unclear [49,52,57,58,60] and one as high risk [48]. Twelve studies were of low risk of reporting bias [48–57,59,60]. Only one study was classed as high risk of bias for this item [58]. Ten studies were ranked as high risk of response and recall bias [49–54,56–58,60]. Risk of compliance bias was evident in three studies [48,49,53]. Another study was judged to be of high risk of analytical bias [58]. Two studies appeared free of other sources of bias [55,59].

Synthesis of results

PA and SB assessed in hours per week or hours per day were converted into minutes per week and minutes per day [52,57]. For the following, intervention group refers to the condition incorporating SMS. An overview of findings including PA and SB outcomes and outcome measures can be found in Table 4. Table 5 shows theoretical frameworks used and effectiveness of intervention groups in each study.

Table 5. Overview of PA and SB outcomes and outcome measures in intervention groups at longest follow-up.

	Accelerometer	Pedometer	Questionnaire	Interview
PA outcomes				
Accelerometer counts/min	↓ [50]			
Light PA min/day	↓ [59]			
MVPA %	↓ [50]			
MVPA min/week			↑ [52] ↑ [56]	↓ [57]
MVPA min/day	↑ [48] ↓ [54] ↑ [55]			
MPA %	↓ [51]			
MPA min/day	↑ [59]			
VPA %	↓ [51]			
VPA min/day	↑ [59]			
MVPA score			⇑ [53]	
4-day step count		↓ [56]		
MVPA MET min/week			↑ [58]	
PA days/week			⇑ [49]	
SB outcomes				
Screen time min/day			↓ [50] ↓ [52] ↑↓ [54]	
TV/computer hours/day			⇓ [49]	
Total SB	↑ [51] ↑ [59] ↑↓ [48] ↓ [55]		⇓ [51] ↓ [57]	
PA less than 360 min/week			↑ [60]	

MVPA = moderate to vigorous physical activity. MPA = moderate physical activity. VPA = vigorous physical activity. MET = Metabolic Equivalent. ↑ *Increase*; ↓ *Decrease;* ⇓⇑ *= Statistically significant (p<0.05) between baseline and longest follow-up.* ⇓⇑ *= Statistically significant (p≤0.01) between baseline and longest follow-up.*

480 Table 6. Theoretical framework and intervention effectiveness for intervention group at
481 longest follow-up for individual studies.
482

	TTM	TPB	SCT	SDT	CCT	N/A
Physical activity						
Brannon et al., 2017					●	
Chen et al., 2017			●			
Dewar et al., 2013			○			
Dewar et al., 2014			○			
Ermetici et al., 2016						●
Lau et al., 2012	●					
Lubans et al., 2012			○			
Mendoza et al., 2017				●		
Newton, Wiltshire & Elley, 2009						○
Patrick et al., 2013	○					
Sirriyeh, Lawton & Ward, 2010		●				
Straker et al., 2014				●		
Sedentary behaviour						
Brannon et al., 2017					○●	
Chen et al., 2017			●			
Dewar et al., 2013			●			
Dewar et al., 2014			○●			
Ermetici et al., 2016						●
Lana, Faya-Ornia & López, 2014	○					
Lubans et al., 2012			●			
Mendoza et al., 2017				●		
Patrick et al., 2013	●					
Straker et al., 2014				○		

483

484 *N/A – No theory framework; ○ Negative effect (PA decrease, SB increase); ● Positive effect*
485 *(PA increase, SB decrease); ● ○ = Statistically significant (p<0.05) between baseline and*
486 *longest follow-up. ● ○ = Statistically significant (p≤0.01) between baseline and longest*
487 *follow-up.*
488

489 **Physical activity**
490 Included studies assessed accelerometer counts [50,54], light PA [59], moderate and/or
491 vigorous PA [48,50–59], step count [56] or the number of days on which a minimum of 60
492 minutes of PA was achieved [49]. Nine studies assessed MVPA [48,50,52–58]. Three studies
493 resulted in a decrease between baseline and longest follow-up for the intervention group

[50,54,56,57]. One study however found an increase in MVPA between 6- and 12-month assessment [57]. In another study, MVPA of normal weight participants increased between baseline and 2-school-year follow-up for the intervention group, however decreased for the control. For overweight or obese participants, MVPA increased in both groups [52]. Four interventions resulted in increases in MVPA for all intervention and control groups between baseline and follow-up [53,55,56,58]. Two studies assessing MVPA used different types of SMS [48,58]. TMs sent by parents were effective in increasing MVPA for 70% of participants. SMS sent by a peer for 50% and those sent from a behavioural health specialist for 90% of participants. Overall, the intervention resulted in higher levels of PA than during the control condition [48]. Another study employed neutral, affective, instrumental or a combination of affective and instrumental SMS [58]. Across all participants, MVPA increased during the 2-week intervention with affective SMS resulting in the highest levels of PA undertaken [58]. In two studies, MPA and vigorous PA (VPA) were assessed [51,59]. Total, during school, after school and weekday MPA and VPA decreased from baseline to 12-week follow-up for both intervention and control group [51]. The other study showed increases in MPA and VPA between baseline and 12 months [59]. For the intervention group, one study found an increase in PA levels between baseline and 3 months and between baseline and 6 months. PA levels decreased in the control condition [49]. Assessments of accelerometer counts, light PA and daily step count showed decreases between baseline and follow-up [50,54,56,59].

Sedentary behaviour

Studies assessed screen time [49,50,52,54], total SB [48,51,55,57,59] and whether participants performed less than 360 minutes of PA per week [60]. Three interventions found a decrease in screen time between baseline and longest follow-up [49,50,52]. One study found an increase in subjectively measured screen time on week days, however a decrease on weekend days [54]. In one intervention [51], subjective SB decreased in the intervention group and increased in the control group between baseline and 12 months. However, objectively measured SB increased for both groups. In two studies [55,57], the intervention groups reduced their total SB between baseline and follow-up, whereas the usual care or control group showed an increase in SB. Another intervention found an increase in SB between baseline and 8 weeks, 3 months, 6 months and 12 months [59]. One intervention resulted in an increase in insufficient PA in the intervention group between

baseline and 9 months although both control groups reduced their level of insufficient PA during the same period [60]. In another study, SB was lowest when receiving SMS from a parent but was highest when receiving them from a behavioural health specialist, followed by SMS from a peer [48].

Discussion

Summary of evidence

The current review found promising evidence regarding the effectiveness of interventions using SMS to improve PA and SBs. Four out of five studies assessing MVPA via self-report found an increase in PA [52,53,56,58] whereas for objectively assessed MVPA, two interventions showed an increase [48,55] and one a decrease [50,54]. Four studies resulted in a decrease for objectively assessed accelerometer counts, light PA, MPA, VPA and step count [50,51,56,59]. One intervention showed an increase in objectively measured MPA and VPA [59]. Five studies assessing screen time and total SB using questionnaires demonstrated improvements [49–52,57] whereas objectively measured total SB increased in three [48,51,59] and decreased in two studies [48,55]. Of 10 interventions involving PA assessment, 8 resulted in an improvement of at least one PA outcome and of 8 assessing SB outcomes, 5 showed improvements.

Most interventions included in this review focused on increasing PA, whereas elements targeting SB were scarce. Evidence suggests that distinct assessment and approaches are required to improve PA and SB [61,62]. Previous meta-analyses have shown greater SB improvements in interventions solely targeting SB compared to lifestyle interventions, PA interventions or combined PA and SB interventions [63,64]. The evidence reviewed herein found a lack of specific SB components. To increase intervention effectiveness, future studies should consider distinct approaches to improve SB and PA in order to maximize the effectiveness of interventions developed to improve both behaviours.

The evidence presented in this review noted a variety of different outcome measures, which led to conflicting findings. Whilst objective measures showed improvements in PA in 3 studies, subjective measures resulted in improved PA in 5 studies. Objectively assessed SB improved in 1 study, whereas subjectively assessed SB improved in 5 studies. This is in line

with previous findings showing subjective measures demonstrate greater enhancements in SB than objective measures [65]. It appears that to assess effectiveness, objective measures are preferred, whereas for the assessment of the nature and mode of activity being undertaken, subjective measures should be used [61,66]. We also noted that a variety of protocols for the assessment and evaluation of participant data had been used. It has been shown that the choice of data reduction protocol when analysing accelerometer data has a significant effect on the classification of SB and PA time in children [67]. There is a continued need for the standardisation of methods when using objective measures to assess PA and SB [61] and future studies should consider following current recommendations on the assessment of both PA and SB to enhance the comparability of findings between studies.

Self-report measures demonstrate low to moderate validity for PA in children and adolescents [66] whereas SB includes a number of different behaviours that can be intermittent and incidental making the accurate assessment of this behaviour challenging [68]. As accelerometers have been validated and increasingly used to estimate both PA and SB [66] we suggest, where possible, that objective measures are used to estimate these behaviours in future studies. Moreover, we would caution against future systematic reviews or meta-analysis including studies which have used different tools to estimate PA and SB. As contrasting findings and conclusions can arise between studies when using objective and subjective measures for capturing PA and SB, conclusions surrounding the effectiveness of mHealth interventions using SMS alone may be biased.

Identified studies also used a variety of theoretical frameworks with the more frequent use of the TTM and SCT, consistent with the findings of others [29]. Interventions informed by SDT, TPB or CCT showed improvements in PA whereas interventions informed by the TTM, SCT and CCT revealed mixed results for PA and SB. SCT appears to increase effectiveness when targeting SB, however not for PA. Nonetheless, the lack of information provided on how theory was applied within the intervention precludes our ability to confirm these assumptions with certainty. These findings are in line with those of a recent meta-analysis [44] which stated it was unclear how specific theoretical frameworks are applied or how they are linked to intervention effectiveness. Thus, our findings do not allow for a judgement

on whether the ineffectiveness of some interventions included in this review is due to a lack of appropriate theory-derivation and -application.

Evidence has shown increased effectiveness of PA and SB interventions that include the BCTs of goal-setting, self-monitoring and feedback [69]. In this review, seven studies included goal-setting and monitoring with five showing an increase in PA [48,49,53,55,59]. Two studies additionally included feedback and achieved improvements in PA [48,53]. Four studies including self-monitoring and goal-setting found an improvement in SB [48,49,55,57]. These results are promising and indicate increased intervention effectiveness when including these BCTs in SMS-based interventions targeting PA and SB.

Previous reviews have shown weaknesses in the design of mHealth interventions [28,29,36,44]. Our findings are in agreement with those reviews and suggest that SMS-based interventions involving adolescents are weak in design and at high risk of bias. The reasons for the high risk of bias was attributed to the use of self-report measures (response bias), a lack of appropriate randomisation method (selection bias) and a lack of blinding (detection bias) which were judged as high in some studies. We were also unable to infer the independent effect of SMS due to the lack of appropriate control groups. In most studies this was due to the inclusion of a variety of additional intervention components alongside SMS in the intervention and control groups. Definite conclusions with regards to the effectiveness of individual intervention designs, settings or contents can therefore not be drawn from this review. Future research should employ study designs that allow the examination of the independent effect of SMS on PA and SB to strengthen the evidence base regarding effectiveness of using SMS alone. Additionally, there is a need for studies exploring which specific text-messaging components such as content or frequency of delivery are most effective.

There is also a continued demand for studies to explore long-term intervention effects on PA and SB [24,28,32,35,37,43]. Only four interventions lasted for 12 months or longer [50–52,54,57,59]. Two studies assessed PA and SB after 24 months [50,52], with only one showing improvements in PA [52], but both showing decreases in SB [50,52]. It has been shown that SMS may be an effective tool to enhance participant interest in the long-term as

well as to improve adherence [31,36]. Therefore, more studies should explore the effectiveness of interventions in achieving sustained behaviour change.

The current review shows high heterogeneity of study designs, intervention components, outcomes and outcome measures. Possible conclusions regarding effective intervention designs and contents are therefore limited and should be drawn with caution. The authors suggest that future mHealth interventions incorporate the following elements to increase effectiveness of SMS-based PA and SB interventions for adolescents. These include:

- Specific focus on desired behaviour
- Use of objective outcome measures
- Include long-term follow-up
- Use of SCT when targeting SB
- School- or web-based intervention when targeting SB
- Include self-monitoring, goal setting and feedback components
- Combine SMS with mobile app
- Send 3 or more SMS per week for PA.

Limitations

The authors were unable to conduct a quantitative data synthesis due to high heterogeneity of included studies and a small pool of suitable data consisting of highly heterogeneous interventions and outcome measures. The current review included all studies incorporating SMS as part of their intervention which resulted in a variety of intervention designs and contents. Consequently, we were unable to draw conclusions with regards to specific intervention elements positively influencing PA and SB. To the best of our knowledge this review provides the first account of interventions using SMS targeting PA and SB in adolescents. It provides researchers and practitioners with a database of potentially effective components crucial for the development of successful behaviour change interventions.

Existing reviews have employed methods to identify and code theory-based elements such as behaviour change techniques of included studies [26,28,65]. The current review has

refrained from following this process for studies not specifying theory base. However, the authors of those studies were contacted and a lack of theoretical foundation was confirmed. Despite the possibility that these interventions were unintentionally and unknowingly based on theory, there was no overt application of theory to study design. Therefore, it is judged to have limited contribution to intervention effectiveness. The authors conclude that while assessment of theory used in interventions not specifically specifying doing so is interesting, an influence of theory not employed intentionally on intervention effectiveness is limited.

This current review does provide a detailed account of the use of theory in SMS-based interventions involving adolescents which, to the best of our knowledge, is novel and crucial to understanding current trends in intervention design and content. Moreover, a rigorous methodology was used for acquiring suitable studies as well as during the data extraction process. This included hand searching bibliographies, contacting authors of eligible studies, following recognised guidelines during data extraction and pilot testing data extraction items. Existing reviews on technology-based interventions targeting health behaviour change have failed to include one or more of these components [24–31,33,35,37,43,44].

Conclusions

The current review shows a high level of heterogeneity within SMS-based interventions targeting adolescent PA and SB. The evidence base consists of studies using different objective and self-report outcome measures that employ a variety of protocols which impairs the ability to synthesise study content and results. Additionally, assessment of risk of bias showed some limitations in study and intervention design. Results of individual as well as across studies should therefore be analysed with caution. Future research should employ more rigorous research designs, more structured and coherent intervention components as well as more appropriate and valid outcome measures. Overall, the current findings indicate that multi-component interventions incorporating SMS can be effective in improving PA and SB in adolescents, however more evidence is needed to further warrant SMS interventions to improve PA and SB.

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Conflicts of interest

None declared.

Abbreviations

BCT	Behaviour change technique
CCT	Cybernetic Control Theory
MET	Metabolic Equivalent
mHealth	Mobile Health
MPA	Moderate physical activity
MVPA	Moderate to vigorous physical activity
PA	Physical activity
SB	Sedentary behaviour
SCT	Social Cognitive theory
SDT	Self-determination theory
SMS	Short message service
SOC	Stage of Motivational Readiness for Change
TPB	Theory of Planned Behaviour
TTM	Transtheoretical model
VPA	Vigorous physical activity

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